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(54) Leaking manifold seal

(57) A fuel cell stack has external reactant gas manifolds pressed against its sides with seal material disposed between the sides of the stack and each manifold. The stack is disposed within a pressure vessel. An inert gas is fed into the pressure vessel at a pressure slightly above the pressure of the reactant gases within the stack. The inert gas continuously leaks into the reactant gas manifolds past the seal material, thereby preventing leakage out of the manifolds.

FIG. 1

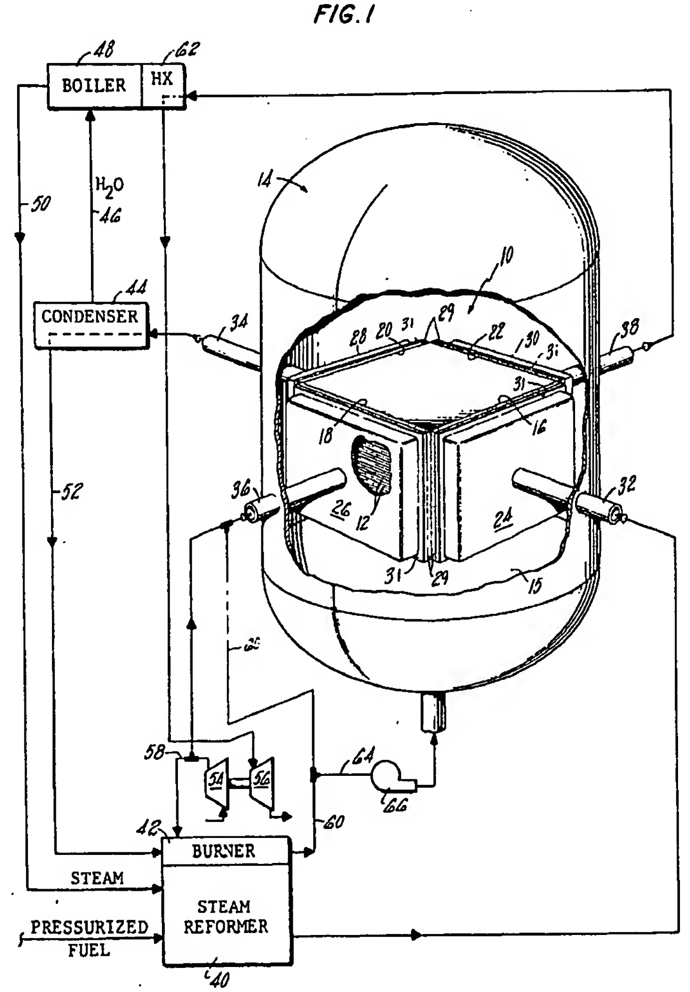

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FIG. 1

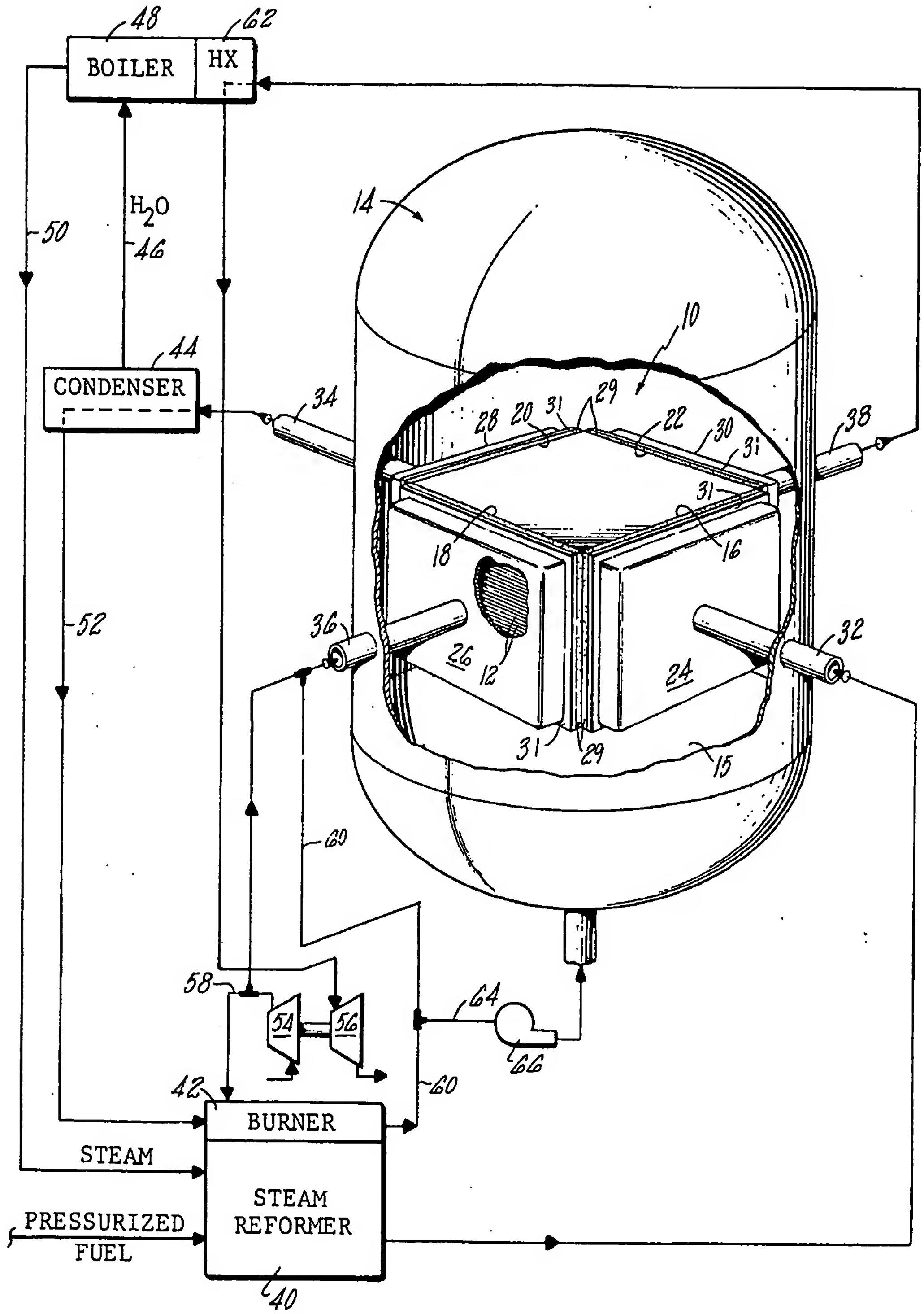
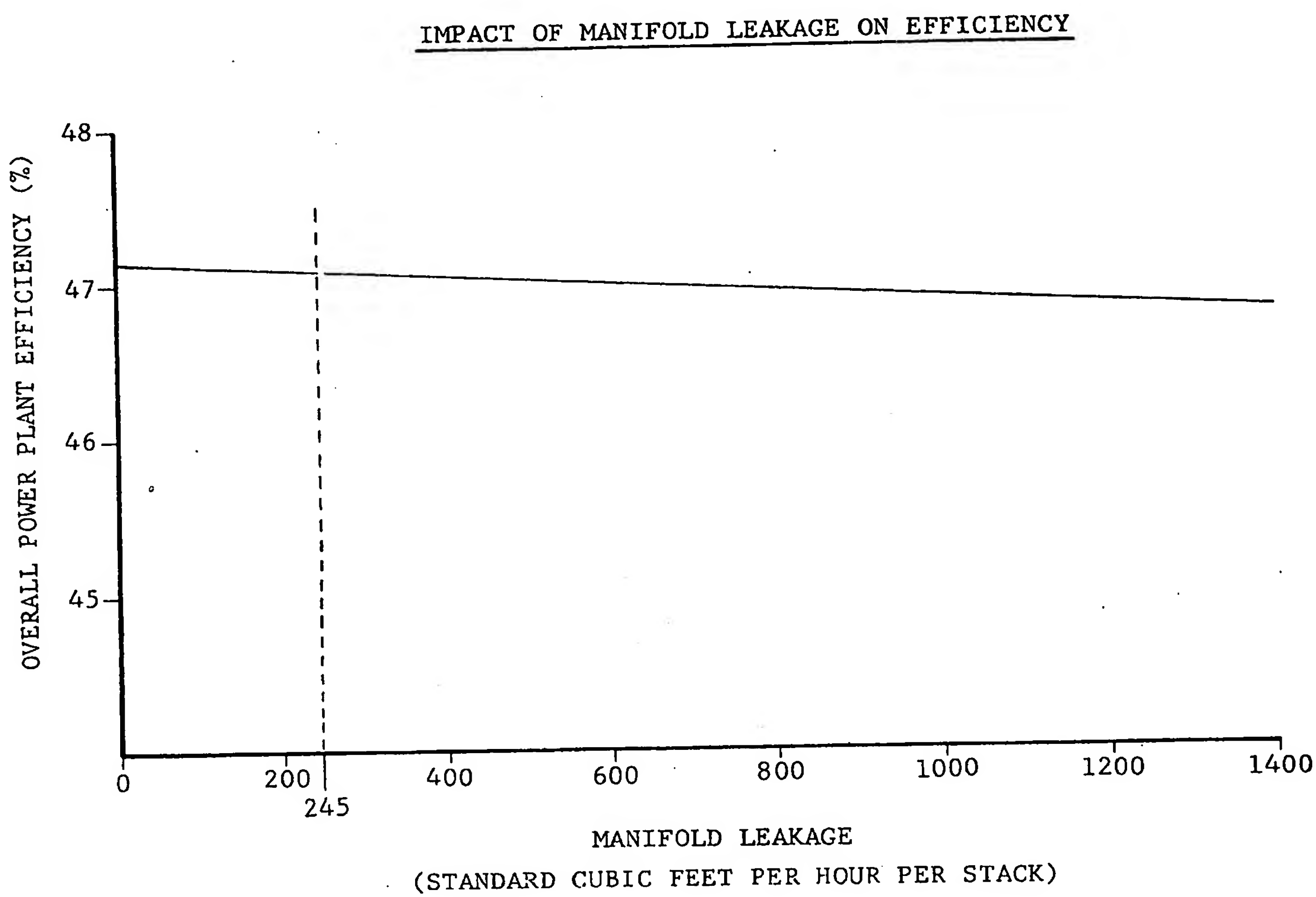

BOILER
HX
48
62
H2O
46
50
14
10
44
CONDENSER
34
28
20
31
29
22
30
31
38
31
18
16
52
36
26
12
24
32
31
29
15
60
58
54
56
64
66
42
60
BURNER
STEAM
STEAM REFORMER
PRESSURIZED FUEL
40

FIG. 2


IMPACT OF MANIFOLD LEAKAGE ON EFFICIENCY
OVERALL POWER PLANT EFFICIENCY (%)
48
47
46
45
0
200
245
400
600
800
1000
1200
1400
MANIFOLD LEAKAGE
(STANDARD CUBIC FEET PER HOUR PER STACK)

SPECIFICATION

Leaking manifold seal

Technical field

This invention relates to fuel cell systems.

Background art

Fuel cell systems, such as fuel cell power plants for generating electricity, typically comprise a large number of fuel cells arranged one atop the other and connected electrically in series to form a stack. A fuel cell system may contain any number of stacks. Reactant gas manifolds are used to convey reactant gases to the cells and to receive depleted reactant gases from the cells. These manifolds are secured tightly against the side surfaces of the stack, and a compressible sealing material or gasket is disposed between the surface of the stack and the edge of the manifold in an effort to prevent leakage of reactant gases from the manifolds. Figures 1 and 2 of commonly owned U.S. Patent No. 4,345,009 show a stack of phosphoric acid electrolyte fuel cells having external reactant gas manifolds secured to the sides thereof.

The ability to positively seal the edges of the manifolds against the surfaces of the stack is dependent upon several factors including the pressure of the reactant gases, operating temperature, and the type of electrolyte used in the cells. This limits the materials which may be used for sealing. There may also be a limitation as to the amount of force which can be used to press the external manifolds against the stack surfaces.

Molten carbonate electrolyte fuel cells may operate at temperatures on the order of 649°C and at reactant gas pressures on the order of 9.9 bar or even higher. If operating at above atmospheric pressure, the stack is disposed within a pressure vessel. It is very difficult to completely prevent the escape of reactant gases from the manifolds under those conditions, although it is necessary to do so to prevent the buildup of combustible gases within the pressure vessel surrounding the stack and to maintain high efficiency.

Disclosure of invention

It is an object of the present invention to prevent leakage of reactant gases from a fuel cell stack having external reactant gas manifolds.

According to the present invention, a fuel cell stack with external manifolds includes seals between the manifolds and the stack surfaces and is disposed within a pressure vessel which is continuously fed an inert gas at a pressure greater than the reactant gas pressure inside the stack, wherein the inert gas within the pressure vessel continuously leaks past the seals into the reactant gas manifolds.

The fuel cell system of this invention, rather than attempting to prevent leakage, allows leakage; however, the system assures that such leakage is into the reactant gas manifolds rather than out of the reactant gas manifolds, and that such leakage is virtually harmless to the system. This eliminates the difficult task of creating a positive seal in a very hostile environment.

The invention is particularly well suited for use with molten carbonate electrolyte fuel cell systems, since it has not been possible to create a nonleaking external manifold seal for that type of fuel cell stack.

The term "inert gas" as used herein means a gas having no constituents which are present in sufficient amounts to be harmfully reactive to the stack components, and which gas does not significantly reduce cell performance as it passes through the stack. Thus, for safety purposes, the inert gas can have no significant amounts of oxidizing or oxidizable constituents (e.g., O_2, C1, CO, CH_4 and H_2) which would react at the operating temperatures of the cell, since the combination of these constituents can result in an explosion. Constituents which would accelerate corrosion of cell or manifold components are also not allowed.

In a preferred embodiment the fuel cells of the stack use molten carbonate electrolyte; and depleted fuel gas passes from the fuel outlet manifold and is burned to remove virtually all the combustibles, such as carbon monoxide, unreacted hydrogen, and other hydrocarbons. That burned gas, or a portion of it, is then introduced into the pressure vessel as the inert gas. It has been shown in tests of several 10 to 20 cell stacks having 0,09 m² cells that the leakage of an inert gas into the stack through the manifold seals can be maintained at a level which will reduce the fuel cell system efficiency by less than one-tenth of 1%.

The foregoing and other objects, features and advantages of the present invention will become more apparent in the light of the following detailed description of preferred embodiments thereof as shown in the accompanying drawing.

Brief description of the drawing

Figure 1 is a diagram, partly in block form and partly schematic, showing a fuel cell system incorporating the features of the present invention.

Figure 2 is a graph showing the effects of manifold leakage on fuel cell system efficiency.

Best mode for carrying out the invention

As an exemplary embodiment of the present invention, consider the fuel cell system as shown in Figure 1. I this system a fuel cell stack is generally referred to by the reference numeral 10. The stack 10 is comprised of a plurality of fuel cells 12 stacked one atop the other and connected electrically in series. Each of the cells contains molten carbonate electrolyte disposed between a pair of electrodes; adjacent cells are separated by gas impervious electrically conductive plates. The construction of such cells is well known in the art and forms no part of the novelty of the present invention. The stack 10 is disposed within a pressure tight vessel 14. A gas space 15 is thereby defined between the stack 10 and the vessel 14 which surrounds it.

Each of the four stack sides 16, 18, 20, and 22 has a reactant gas manifold 24, 26, 28, 30, respectively, secured thereto, by means not shown, but which could be by straps which wrap around the stack 10 in the manner shown in above-referred to U.S. Patent No. 4,245,009. The manner of securing the manifolds to the stack sides is not considered a part of the present invention. A "picture frame" type gasket seal 29 is sandwiched between each of the side faces 16, 18, 20, 22 of the stack 10 and a peripheral flange 31 of its respective manifold 24, 26, 28, 30. The seals 29 are not gas tight. They may be, for example, ceramic fiber seals which are porous and compressible, and which are virtually inert to molten carbonates of the type generally used as fuel cell electrolyte.

The manifold 24 is the fuel gas inlet manifold which is fed a hydrogen rich gas stream via a conduit 32. The

manifold 24 conveys the fuel gas to the cells 12; and the gas passes across the stack through the cells and is received by the fuel gas outlet manifold 28. Depleted fuel gas (i.e., most of the hydrogen has been reacted) leaves the manifold 28 via a conduit 34. The manifold 26 is the oxidant gas inlet manifold. It receives oxidant gas via a conduit 36 and conveys it to the cells 12. The oxidant gas travels across the stack through the cells in a direction perpendicular to that of the fuel gas and is received by the oxidant gas outlet manifold 30. Depleted oxidant gas leaves the manifold 26 via a conduit 38.

In the simplified fuel cell system of Figure 1, a carbonaceous feedstock, which may be a liquid or gaseous hydrocarbon, is pressurized by means not shown to the pressure at which the fuel cells are to operate. (The cells may operate at atmospheric pressure, but it is advantageous to operate them above atmospheric pressure). This fuel, along with steam at the same pressure, is introduced into fuel conditioning apparatus, such as a steam reformer 40. In the reformer 40 hydrogen is formed by reacting the steam and the carbonaceous feedstock in the presence of a suitable catalyst such as nickel supported on ceramic. Heat for the endothermic reaction is supplied by a burner 42. The hydrogen rich reformed fuel is, by volume, approximately 50% hydrogen, 10% CO, 10% CO_2 and 30% H_2O. This reformed fuel is fed from the steam reformer 40 into the fuel gas inlet manifold 24 of the stack 10 via the conduit 32.

The depleted fuel gas, which leaves the fuel gas outlet manifold 28 via the conduit 34, contains carbon dioxide, unreacted hydrogen, carbon monoxide, and water vapor. This gas stream is passed through a condenser 44 whereupon water is removed via a conduit 46. The water is converted to steam in a boiler 48, and the steam is conveyed from the boiler into the steam reformer 40 via a conduit 50.

Compressed air from a compressor 54, which is driven by a turbine 56, is fed into the oxidant gas manifold 26 of stack 10 via the conduit 36, and is the oxidant gas for the fuel cells 12. As is well known in the art, air does not contain a sufficient amount of carbon dioxide to efficiently drive the fuel cell reaction in molten carbonate electrolyte fuel cells. Thus, the CO_2 portion of the depleted fuel gas effluent is required to be added to the air which is introduced into the stack; but before this can be done, essentially all the combustibles in the depleted fuel gas must be removed. Therefore, the now relatively dry depleted fuel gas is conveyed from the condenser 44 into the burner 42. Compressed air from the compressor 54 is also fed into the burner 42, via a conduit 58. The air provided to the burner and to the oxidant gas inlet manifold 26 is at the same pressure as the fuel entering the steam reformer 40 such that there is a minimal pressure differential across each cell 12; and the pressure within the external manifolds 24, 26, 28, and 30 differs only due to unavoidable pressure drops within the system. The amount of air introduced into the burner 42 is preferably just sufficient to assure substantially complete combustion of the hydrogen, carbon monoxide, and other combustibles, such that the effluent from the burner 42 contains essentially only carbon dioxide, nitrogen, and a small amount of water.

After the oxidant passes through the cells, hot, depleted oxidant gas from the outlet manifold 30 is passed through a heat exchanger 62 to provide the heat for the boiler 48. The depleted oxidant gas stream, which still contains considerable energy, may thereafter be used to power the turbine 56.

In accordance with the present invention, a small amount of the burner effluent from the conduit 60 is diverted into a conduit 64, and is increased slightly in pressure by any suitable means, such as a blower 66. This gas, which is now at a pressure slightly higher than the pressure of the reactant gases fed into the stack 10, is conveyed into the gas space 15 of the pressure vessel 14, and continuously leaks past the seals 29 into the reactant gas manifolds.

As mentioned above, the burner effluent contains essentially only carbon dioxide, nitrogen, and a small amount of water vapor. The nitrogen is, of course, completely nonreactive and noncorrosive within the stack 10. Carbon dioxide leakage into the manifolds is also, of course, harmless, since carbon dioxide is a required constituent of the oxidant gas and is a byproduct of the cell reaction on the fuel gas side of the cell. The water, in small quantities is also harmless. If, for some reason, the effluent from the burner 42 did contain an unacceptable amount of hydrogen or other combustible, or an unacceptable amount of water, then a separate, additional burner and/or condenser could be incorporated into the conduit 64 to further reduce the quantities of these constituents. It is believed that it would be acceptable for the inert gas introduced into the pressure vessel to contain oxygen up to about 1.0%, hydrogen up to about 2.0%, and methane up to about 1.0%. The limiting factor is system efficiency and not concern for exceeding combustible limits.

Figure 2 is a graph which shows the effects of inert gas leakage into the stack manifolds on the overall efficiency of a molten carbonate fuel cell power plant assumed to have stacks comprising 525 cells each, each cell having an approximately 1.44 m² active area. In the graph, manifold leakage is given in m³ per hour, per stack. By scaling up the leakage rate which actually occurred in tests of 20 cell stacks having 0,09 m² cells, it is estimated that the much larger 525 cell stacks would leak at a rate of about 6,94 m³ per hour. From the graph it is seen that at a leakage rate of 6,94 m³/h, the power plant efficiency drops less than one-tenth of 1% (compared to no leakage). The performance penalty associated with even three or four times that leakage rate would be acceptable. One reason the efficiency penalty is so low is that the inert gas used for pressurization, and therefore most of its energy content is not lost to the system. In one test of the present invention a stack of 20 molten carbonate electrolyte cells, each 30,5 cm by 30,5 cm square, was enclosed within a steel pressure vessel. Each of the four sides of the stack had a stainless steel reactant gas manifold secured thereto. A matte of zirconia fibers, 0,254 cm thick, was used as the seal material between the side surfaces of the stack and the outer edges of the manifolds. Reactant gases were fed into the manifolds at 9.8 bar. An inert gas of nitrogen and carbon dioxide in equal portions, by weight, was used to simulate the burner effluent gas. The gas was fed into the pressure vessel at 2,54 to 7,62 cm of water above the pressure of the reactant gases. At steady state operation, when the cells were operating at a temperature of about 649°C, the inert gas from within the pressure vessel was determined to be leaking into the reactant gas manifolds at a rate of about 0,51 m³/h. This

compares to the reactant gas flows into the manifolds of 6,75 m^3/h fuel and 12,1 m^3/h oxidant. The stack operated normally during this test. If run as part of a power plant, the overall power plant efficiency would be reduced by less than 0.1% as a result of inert gas leaking into the reactant gas manifolds at the above-indicated rates. Although the invention has been shown and described with respect to a preferred embodiment thereof, it should be understood by those skilled in the art that the other various changes and omissions in the form and detail thereof may be made therein without departing from the spirit and the scope of the invention.

CLAIMS

1. A fuel cell system comprising
a fuel cell stack comprising a plurality of fuel cells;
external reactant gas manifold means secured to said stack;
gas seal means disposed between said gas manifold means and said stack;
means for conveying fuel cell reactant gases into said manifold means at a first pressure;
characterized by a pressure vessel surrounding said stack and manifold means defining a gas space therebetween;
a source of inert gas; and
means for conveying inert gas from said source into said gas space within said pressure vessel at a second pressure higher than said first pressure;
wherein said gas seal means is constructed and arranged to permit continuous gas leakage therethrough, whereby inert gas continuously leaks from said gas space into said reactant gas manifold means through said gas seal means.

2. The fuel cell system according to claim 1 characterized in that said fuel cells each include molten carbonate electrolyte.

3. A fuel cell system comprising:
a fuel cell stack comprising a plurality of fuel cells each cell including molten carbonate electrolyte;
external reactant gas manifold means secured to said stack, said gas manifold means including a fuel gas inlet manifold for conveying fuel to said cells, a fuel gas outlet manifold for receiving depleted fuel from said cells, an oxidant gas inlet manifold for conveying oxidant to said cells, and an oxidant gas outlet manifold for receiving depleted oxidant from said cells;
gas seal means disposed between said gas manifold means and said stack;
means for conveying fuel gas at a first pressure into said fuel inlet manifold and oxidant gas at said first pressure into said oxidant inlet manifold;
means for conveying at least a portion of the depleted fuel gas from said fuel outlet manifold into said oxidant inlet manifold;
characterized by a pressure vessel surrounding said stack and manifold means and defining a gas space therebetween;
burner means;
means for conveying at least a portion of the depleted fuel gas from said fuel outlet manifold into said burner means to produce an inert gas; and means for conveying at least a portion of the inert gas from said burner means into said gas space within said pressure vessel at a second pressure higher than said first pressure;
wherein said gas seal means is constructed and arranged to permit continuous gas leakage therethrough, whereby inert gas continuously leaks from said gas space within said pressure vessel into said fuel and oxidant inlet and outlet manifolds past said gas seal means.

4. The fuel cell system according to claim 3 characterized by fuel conditioning apparatus external of said pressure vessel for converting a carbonaceous fuel to a hydrogen rich gas, wherein said means for conveying fuel gas into said fuel inlet manifold includes means for conveying the hydrogen rich gas produced in said fuel conditioning apparatus into said fuel inlet manifold, wherein said burner means is in heat exchange relationship to said fuel conditioning apparatus for providing heat thereto.

5. A method of operating a fuel cell system according to claims 1, 2, 3 or 4, including a fuel cell stack comprising a plurality of fuel cells, and fuel and oxidant reactant gas inlet and outlet manifolds secured to the sides of the stack for conveying fuel and oxidant reactant gases to the cells of the stack and for receiving depleted fuel and oxidant reactants from the cells of the stack, wherein the reactants within the manifolds and stack are at a first pressure, and the stack is disposed within a pressure vessel which defines a gas space surrounding the stack, characterized by the steps of:
providing a continuous supply of an inert gas into said gas space at a second pressure higher than the first pressure; and
continuously leaking the inert gas from the gas space into the reactant gas manifolds.

6. The method of operating a fuel cell system according to claim 5 characterized in that the step of providing inert gas into said gas space includes burning at least a portion of the depleted fuel gas to convert it to an inert gas, and conveying at least a first portion of said burned depleted fuel gas into said gas space.

7. The method of operating a fuel cell system according to claim 6 characterized in that each of the fuel cells includes molten carbonade electrolyte including the step of introducing a second portion of said burned depleted fuel gas into the oxidant reactant inlet manifold.

8. The method of operating a fuel cell system according to claim 7 characterized by fuel conditioning apparatus for converting a hydrocarbon fuel to a hydrogen rich gas which is the fuel reactant gas for the cells, wherein the step of burning provides heat to the fuel conditioning apparatus for use in converting the hydrocarbon fuel to a hydrogen rich fuel reactant gas.

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